

1 Introduction and Overview

1.1 Executive Summary

Current and upcoming neutrino oscillation experiments in the United States, Europe and Japan have driven the construction of new, very intense neutrino beamlines required to achieve reasonable event rates at detectors located hundreds of kilometers away. These new beamlines allow us to initiate a vigorous neutrino scattering research program at a detector, located close to the production target, where event rates are much higher than at the previous generation of neutrino beam facilities. Note, furthermore, that it is neutrino oscillation experiments, with their low-energy neutrinos and massive nuclear targets, which highlight the need for much improved knowledge of low-energy neutrino-Nucleus interactions.

At Fermilab, the NuMI beam, designed for the MINOS neutrino oscillation experiment, yields several orders of magnitude more events per kg of detector per year of exposure than the higher-energy Tevatron neutrino beam. With this much-increased intensity, one can now perform statistically-significant neutrino scattering experiments with much lighter targets than the massive iron, marble and other high-A detector materials used in the past. That these facilities are designed to study neutrino oscillations points out the second advantage of these neutrino scattering experiments: An excellent knowledge of the neutrino beam will be required to reduce the beam-associated systematic uncertainties of the oscillation result. This knowledge of the neutrino spectrum will also reduce the beam systematics in the measurement of neutrino-scattering phenomena.

The MINER ν A experiment (Main INjector ExpeRiment: ν -A), a collaboration of elementary particle and nuclear physics groups and institutions, will run in the NuMI beamline, and be sited in the hall which currently houses the MINOS near detector. With considerable available space, the hall is an ideal environment for neutrino experiments. It provides a well-shielded area with sufficient infrastructure to support MINER ν A as well as MINOS.

MINER ν A will complete a physics program of high rate studies of exclusive final states in neutrino scattering including quasi-elastic scattering, and resonant and coherent pion production. MINER ν A will also study the poorly understood transition region between non-perturbative and perturbative QCD in the DIS region and the application of duality with the weak current. MINER ν A will contribute significantly to the study of parton distribution functions (PDFs) in the poorly known high- x_B region as well as quark-flavor dependent studies of generalized parton distributions (GPDs). Studies on several nuclear targets will explore nuclear effects, another topic that has not been studied with neutrinos up to now.

MINER ν A results will also be very important for present and future neutrino oscillation experiments, where the details of neutrino cross-sections and final states as well as nuclear effects are essential in determining the energy of the incoming neutrino and in separating backgrounds to oscillation from signal.

MINER ν A will address all these topics, and bring additional physics focus to the Fermilab neutrino program with a comparatively simple, low-risk detector. MINER ν A is composed of several sub-detectors with distinct functions in reconstructing neutrino interactions. The fiducial volume (approximately 6 tons) for most analyses is the inner “ActiveTarget” where the only material is the sensitive scintillator strips themselves. The scintillator detector does not fully contain events due to its low density and lowZ, so the MINER ν A design surrounds it with sampling detectors; electromagnetic and hadronic calorimeters. The nuclear targets will be located in the upstream end of the detector.

1.2 The MINOS Near Detector Hall

The MINOS Near Detector Hall[1] is a fully-outfitted experimental facility that can accommodate MINER ν A with a limited number of additions to the infrastructure.

The hall is 45 m long, 9.5 m wide, 9.6 m high, with its upstream end just over 1 km from the NuMI target, at a depth of 106 m below grade. The MINOS near detector has been installed at the downstream end of the hall, and there is free space upstream amounting to, roughly, a cylinder 26 m in length and 3 m in radius. The neutrino beam centerline descends at a slope of 3.3° and enters the MINOS detector at a height of 3 m from the floor.

Ground water is pumped from the NuMI/MINOS complex at a rate of approximately 200 gallons (750 l) per minute. The hall floors and walls are occasionally damp in places, and a drip cover will be used to protect MINER ν A from moisture. The air is held at a temperature between 60° F and 70° F (15° C and 21° C), and 60% relative humidity.

1.2.1 Utilities

The MINOS Service Building on the surface houses the access shaft to the Near Detector Hall and is the entry point for electrical, cooling, and data services to the hall. A 15-ton capacity crane, with a hook height of 18.5 feet (5.66 m), was used to lower the 3.47 ton MINOS detector planes to the hall. MINOS planes were moved within the hall using an overhead 15-ton crane, with 22 foot (6.7 m) hook height and a coverage along the beam axis of approximately 40 m. The procedure for installing MINER ν A will closely follow that used by MINOS.

Quiet power to the hall is provided by a 750 KVA transformer at the surface, which branches to a 45 KVA transformer for the muon monitoring alcoves, and two 75 KVA transformers for the Near Detector hall. The power needs of the MINOS detector account for the capacity of the 4 panelboards served by the two 75 KVA transformers. The estimated power consumption of MINER ν A's electronics is around 5000 W. MINER ν A will require an additional 75 KVA transformer as well as additional panelboards. Both the transformer and panelboards have been installed by Fermilab.

The heat sink for the MINOS LCW cooling circuit is the flux of ground water collected in the MINOS sump. This cooling is adequate for MINOS, with an output water temperature of 70° F. The relatively low heat load of the MINER ν A electronics will likely be absorbed without problem by the MINOS hall air conditioning.

1.2.2 Detector placement

The downstream face of the last MINER ν A plane will be placed 2.0 m upstream of the upstream face of the first MINOS plane. This will leave sufficient work space between the two detectors and will avoid interfering with the MINOS coil, which extends approximately 1.7 m upstream of MINOS, to the lower right in the view of Figure 1. To have the beam axis intersect the detector axis close to the center of the active plastic target, the lowest corner of MINER ν A will be placed 1.10 m above the hall floor. The beam centerline will enter the detector at an elevation of 3.4 m from the floor (Figures 2 and 3).

1.2.3 Impact on MINOS

The impact of MINER ν A on the MINOS installation has been and will continue to be minor. The power supply for the MINOS coil had to be moved upstream and the stairway accessing the upper MINOS

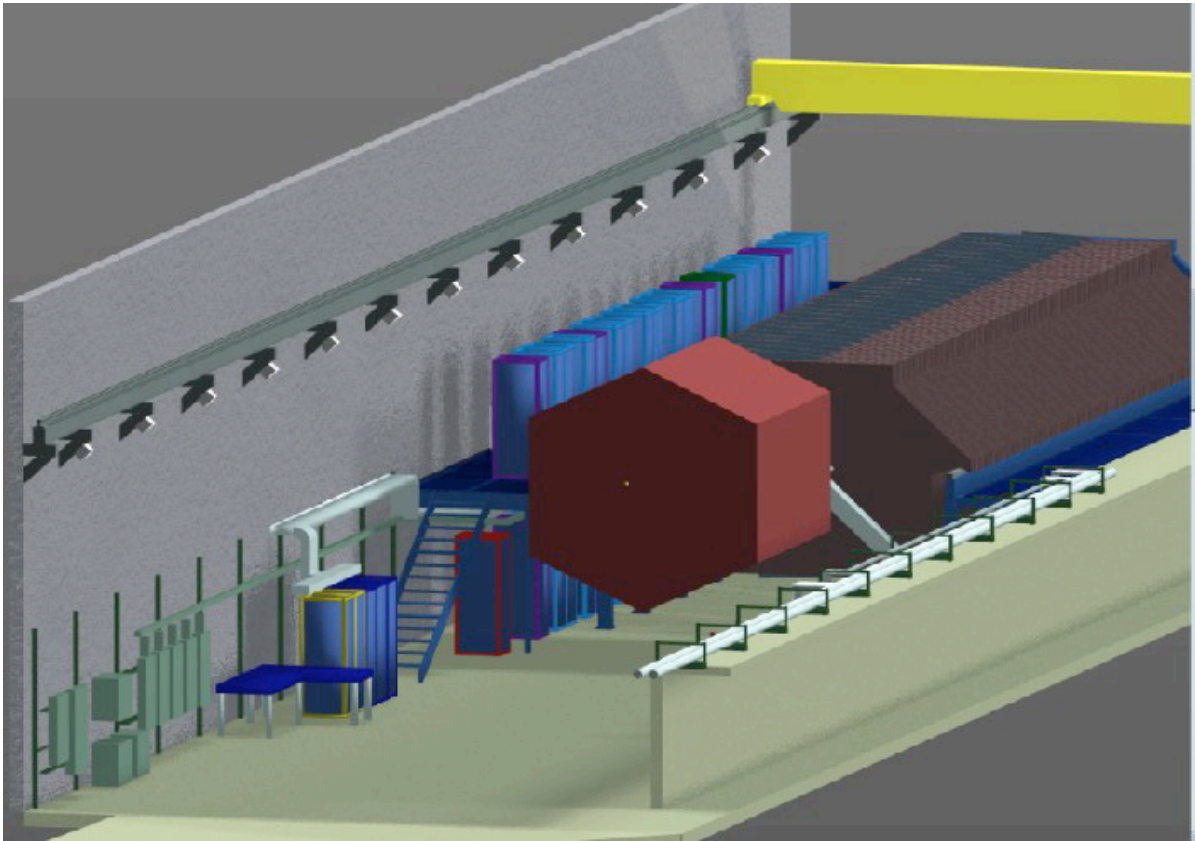


Figure 1: View of the proposed MINERνA detector, and the MINOS detector, looking downstream.

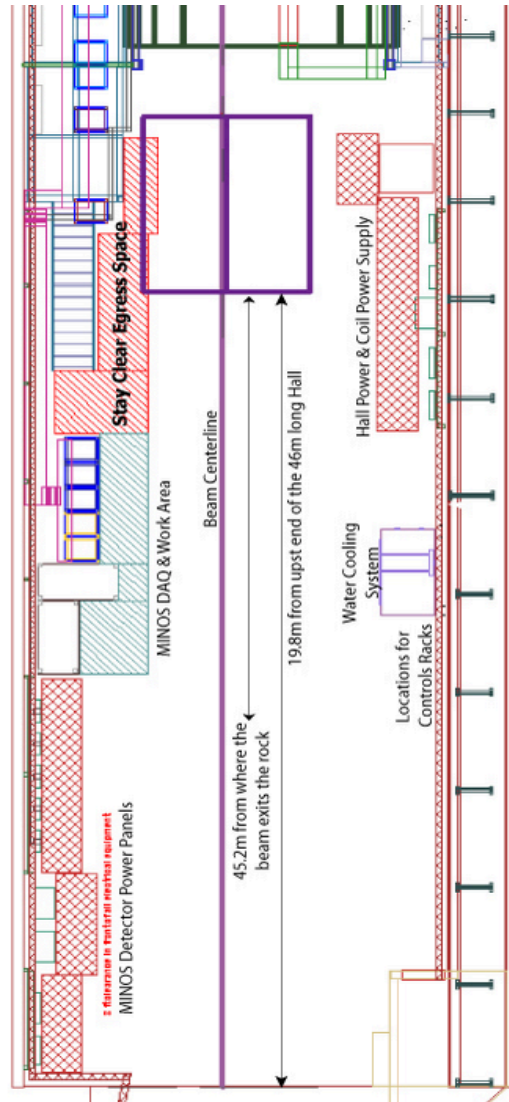


Figure 2: Plan view of MINERvA (purple outline near top of figure).

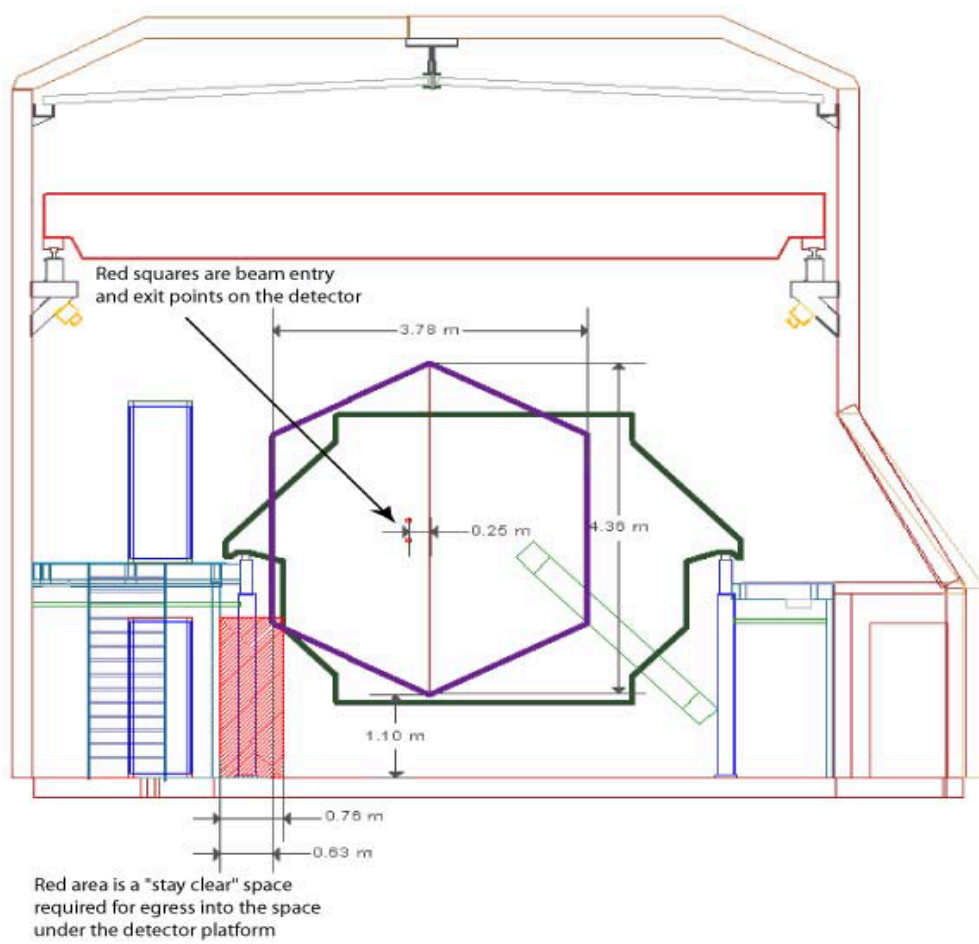


Figure 3: Front view of MINERvA.
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electronics racks had to be moved. The drip-ceiling covering the MINOS experiment will be extended to also cover MINER ν A during an upcoming Fermilab shutdown.

The presence of the detector in the neutrino beam will cause an increase in the rate of activity in the MINOS detector, mainly in the first (upstream) 20 planes forming the MINOS veto region. Given MINER ν A's total mass of ≈ 200 tons, for the majority running of the MINOS experiment that uses the lowest energy NuMI beam tune, the expected event rate in the detector is ≈ 1.2 charged-current interactions per 10^{13} protons on target (POT). For a spill of 2.5×10^{13} POT this corresponds to 3.0 charged-current events, plus an additional 1.0 neutral-current event per spill. Combining the excellent timing resolution of both MINER ν A and MINOS with the fact that the vectors of all particles leaving MINER ν A with a trajectory heading towards MINOS will be made available when MINER ν A is taking data, this rate should be easily manageable. Even when running the NuMI beam in the higher energy tunes, the increase in rate should be ≤ 3.5 , and that is still manageable.

1.3 The NuMI Beam and MINER ν A Event Sample

The NuMI neutrino beam is produced from π^- and K^- -decay in a 675 m decay pipe beginning 50 m downstream of a double horn focusing system. At the end of the decay pipe a 10 m long hadron absorber stops the undecayed secondaries and non-interacting primary protons. Just downstream of the absorber, 240 m of Dolomite is used to range out muons before the ν beam enters the Near Detector Hall. Figure 4 shows the beamline and hall layout.

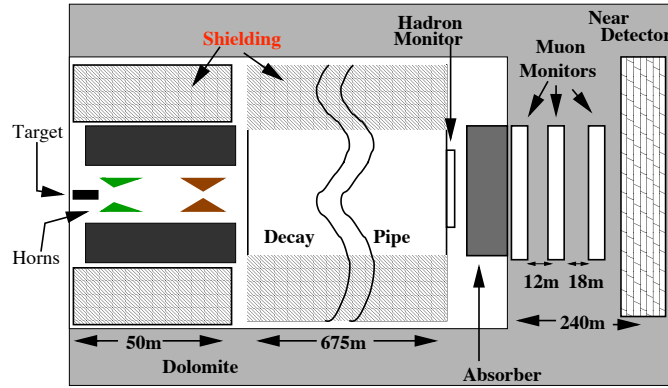


Figure 4: Layout of NuMI beamline components and near detector hall (not to scale).

1.3.1 Energy options

The neutrino energy spectrum of the NuMI beam can be adjusted by changing the distances of the target and second horn from the first horn, as in a zoom lens. The three standard configurations result in three beam energy tunes for the low- (LE), medium- (ME), and high-energy (HE) ranges respectively. However, to switch from one beam mode to another requires down-time, to reconfigure the target hall, and a consequent loss of beam time. An alternative procedure, which also allows the peak energy to be varied, is to change the distance of target from the first horn and leave the second horn fixed in the LE position. Although the resulting event rates are lower in comparison with those involving the movement of the second horn (ME and HE), the movement of the target can be accomplished remotely

and quickly with a maximum target excursion of -2.5 m upstream of the first horn from its nominal low-energy position. Moving the target -1.0 m results in a “semi-medium” energy beam tune (sME), and -2.5 m produces a “semi-high” energy beam (sHE). A considerably more efficient sHE beam is possible with three-day downtime to move the target to its normal HE position of -4.0 m. This more efficient sHE(-4.0) beam would yield over 50% more events than the sHE(-2.5) beam.

When MINER ν A is running parasitically with MINOS, the beamline will be operating primarily at its lowest possible neutrino energy setting, to reach the lowest values of Δm^2 . However, to minimize systematics, MINOS will also run in the sME and sHE configurations. The neutrino energy distributions for the LE, sME, and sHE running modes are shown in Figure 5.

When MINER ν A is running parasitically with NO ν A the beamline will be operating in the medium energy - ME- configuration.

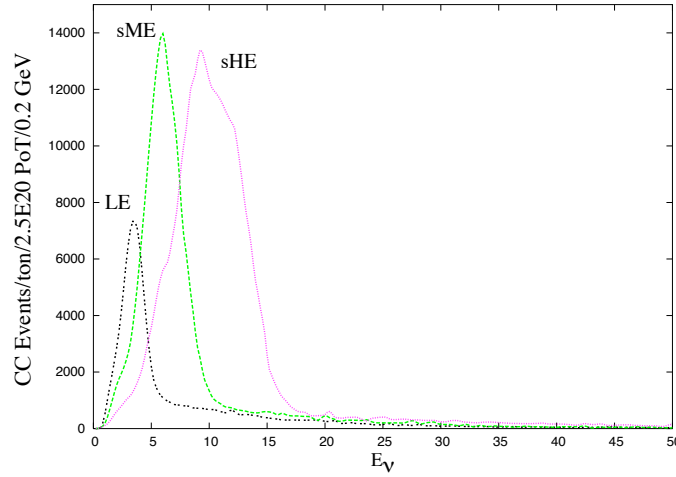


Figure 5: Neutrino energy distribution for charged-current interactions in three configurations of the NuMI beam corresponding to low-energy (LE), medium-energy (sME) and high-energy (sHE).

1.3.2 MINER ν A event rates

Table 1 shows charged-current interaction rates per 10^{20} protons on target (PoT) per ton for different neutrino beam energy configurations.

The same beam configurations with horn-currents reversed focus π^- to create anti-neutrino beams. The $\bar{\nu}_\mu$ charged-current interactions from anti-neutrino configurations (LErev, MErev, and HErev) are of great interest and would be highly desirable for MINER ν A’s physics program.

Beam	CC ν_μ
LE	60 K
ME	235 K
sME	132 K
sHE	212 K

Table 1: MINER ν A charged-current interactions per ton, per 10^{20} protons on target.

1.3.3 Baseline MINER ν A run plan

The baseline MINER ν A four-year run plan assumes one year running parasitically with MINOS in the LE beam and 3 years running parasitically with NO ν A in the ME beam. The assumed protons-on-target for each of the four years is 4×10^{20} PoT. With this 4-year run plan, the total expected charged current event rate is ≈ 2.9 million per ton of detector and the event rates per ton for each CC physics-channel is shown in Table 2. As will be described in detail in the MINER ν A Project section of this report, the fiducial volume of the fully-active central detector will be 3 tons while the fiducial volume of the nuclear targets will be 0.14 ton, 0.69 ton and 0.86 ton for C, Fe and Pb respectively.

Process	CC/ton	NC/ton
Quasi-Elastic	270 K	90 K
Resonance	530 K	165 K
Transition	670 K	210 K
DIS	1370 K	400 K
Coherent	28 K	14 K
Total (ν)	2870 K	880 K

Table 2: MINER ν A samples per ton for various processes assuming the 4-year run plan described in the text.

1.3.4 Precision of neutrino flux prediction

In addition to huge event rates, one of MINER ν A’s significant advantages over previous wide-band neutrino scattering experiments will be better knowledge of the neutrino flux and energy spectrum. Since the NuMI beamline is designed for the MINOS oscillation experiment, considerable effort has been devoted to control of beam-related systematic uncertainties.

The largest source of uncertainty in the neutrino energy spectrum arises from the hadron (π^\pm and K) production spectra. To reduce this uncertainty, a dedicated Fermilab experiment called MIPP (E-907)[7, 4] is directly measuring these hadron production spectra for various nuclear targets. One of the E-907 measurements has been to expose of the NuMI target itself to the 120 GeV Main Injector proton beam. Using the NuMI target material and shape, E-907’s data will include secondary and tertiary hadron production, which significantly modifies the spectra relevant for neutrino production. With input from E-907, the bin-to-bin energy spectrum should be known to $\approx 2\%$ and the absolute neutrino flux should be known to $\approx 5\%$.

For the absolute flux of neutrinos, a second uncertainty concerns the number of protons on target. With the current NuMI primary proton beamline instrumentation[8], the number of protons on target will be known to within (1 - 1.5)%, the range being determined by control of the drift in the proton beam toroid devices.

References

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